

The ND Conceptual Design Report Status

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DUNE LBNC Meeting

December 6, 2019

History of the ND document(s) ...

- Original (Fall '18) thought was of a relatively short document
- Early on we referred to it as the ND executive summary
- LBNC hunger for detail plus much help from subsystem proponents meant ...
- The baby grew up fast, and we let it morph into a "CDR-lite".
 - First version for LBNC appeared in May, followed by the **very helpful ND mini-review** in early June.
- The TDR executive summary has a ND section that summarizes this "CDR-lite".

History of the ND document(s) ...

- Since mid-summer, the document has evolved slightly
 - Made many small corrections and clarifications in response to Sept. feedback
 - The reference design for the 3DST-S (beam monitor) was changed to reflect the use of the KLOE magnet and ECAL
 - Additional small corrections in response to Nov. feedback. Some reconfiguring of appendices (apologies for delay in that, some confusion during execution on our part).
- Now in process of making transition to the CDR, i.e., updated and intended to be more complete and coherent

ND CDR: planned schedule, layout

- December 2019, new input from groups/studies
- January 2020, major editing push, begin internal reviews
- February 2020, revise and edit using internal review feedback
- March 2020, version ready for LBNC

Expect something like this:

- 1) Introduction – 20 pages
- 2) Liquid Argon TPC – 25 pages
- 3) Multipurpose detector – 25 pages
- 4) SAND – 25 pages
- 5) The PRISM concept – 25 pages
- 6) Neutrino Flux Measurements – 10 pages
- 7) Neutrino cross-section measurements – 10 pages
- 8) BSM physics using the ND – 10 pages
- 9) The ND hall and facilities – 10 pages
- 10) Computing for the ND – 2 pages
- 11) Summary of requirements – 5 pages

The role of the ND

- The ND provides the control samples for the oscillation analysis
- Measures the neutrino energy spectrum before oscillations occur
- The measured rate is a convolution of three ingredients:

$$\text{ND Rate} = \int [\text{Flux}] \times [\text{CrossSection}] \times [\text{Det.Response}]$$

- The ND must allow the experiment to predict the FD spectrum:

$$\text{FD Rate} = \int [\text{OscProb}] \times [\text{Flux}] \times [\text{CrossSection}] \times [\text{Det.Response}]$$

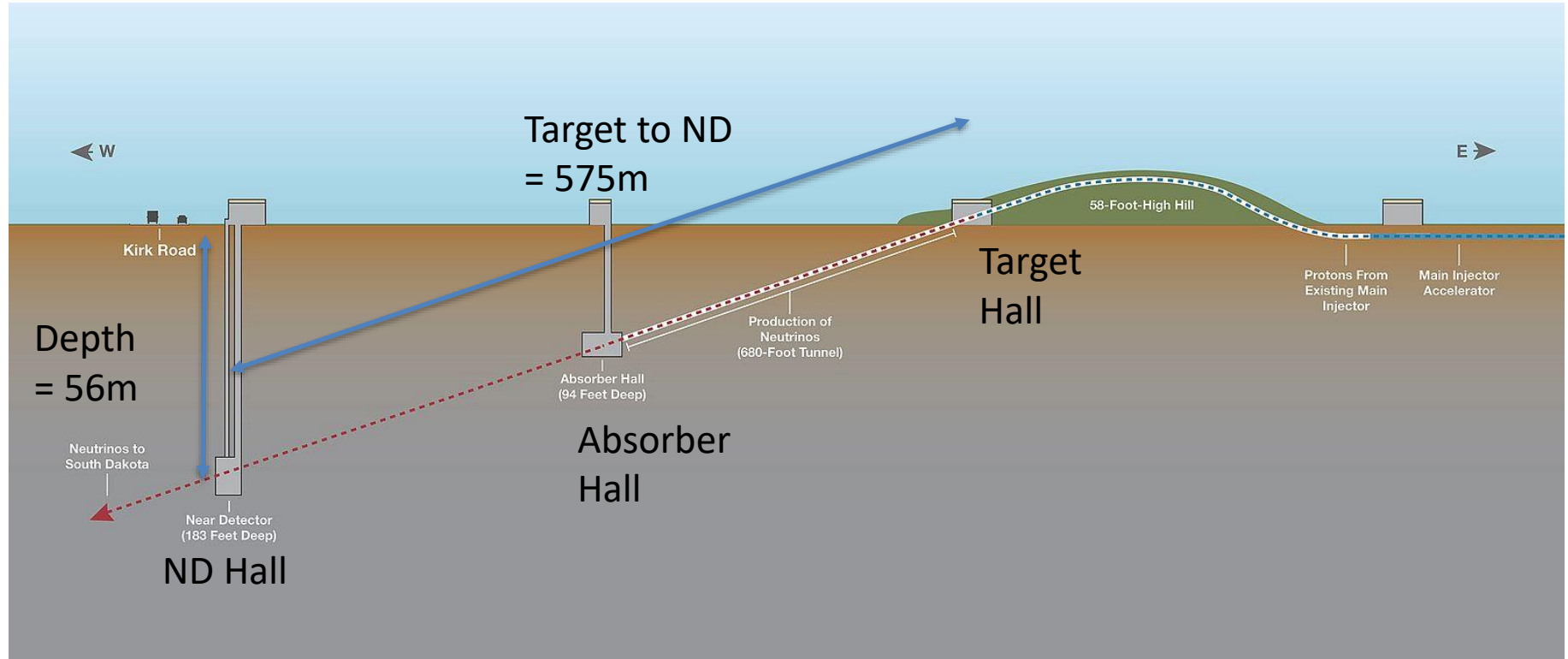
- The ingredients are not necessarily well known. The ND must have the ability to deconvolve them to make the FD prediction and to set systematic errors confidently.

Overarching ND Requirements

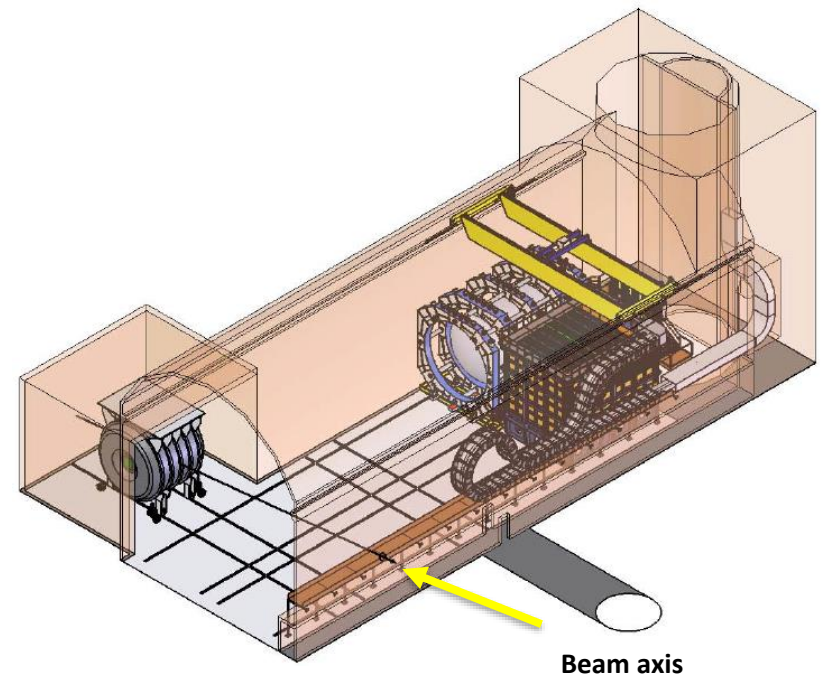
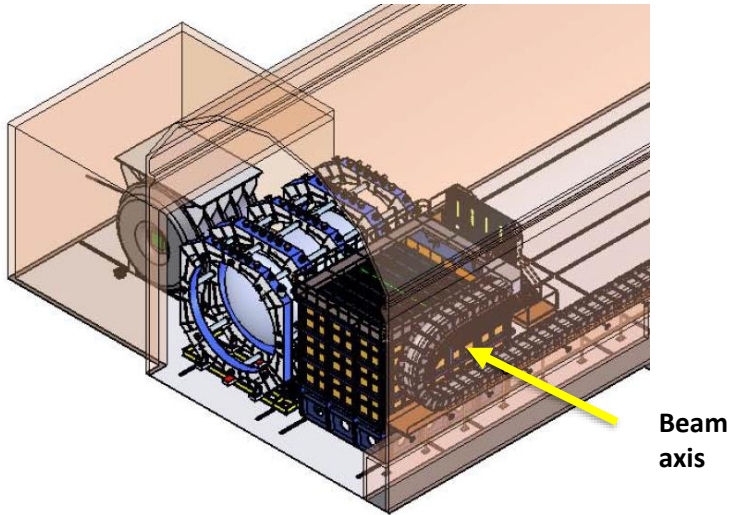
00: Predict the neutrino spectrum at the FD: The Near Detector (ND) must measure neutrino events as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy event spectra from the ND to the FD.

O0.1	Measure interactions on argon	Measure neutrino interactions on argon, determine the neutrino flavor, and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	Measure the neutrino energy	Reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution.
O0.3	Constrain the xsec model	Measure neutrino cross-sections in order to constrain the cross section model used in the oscillation analysis.
O0.4	Measure neutrino flux	Measure neutrino fluxes as a function of flavor and neutrino energy.
O0.5	Obtain data with different neutrino fluxes	Measure neutrino interactions in different beam fluxes in order to disentangle flux and cross sections and verify the beam model. (PRISM)
O0.6	Monitor the neutrino beam	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales.

DUNE near site



DUNE near detector



System for on-Axis
Neutrino Detection
(SAND)

Beam
monitor
(00.6)

Neutrons and
xsec model

Multi-purpose
Detector (MPD)

Momentum
analyze CC
event in LAr

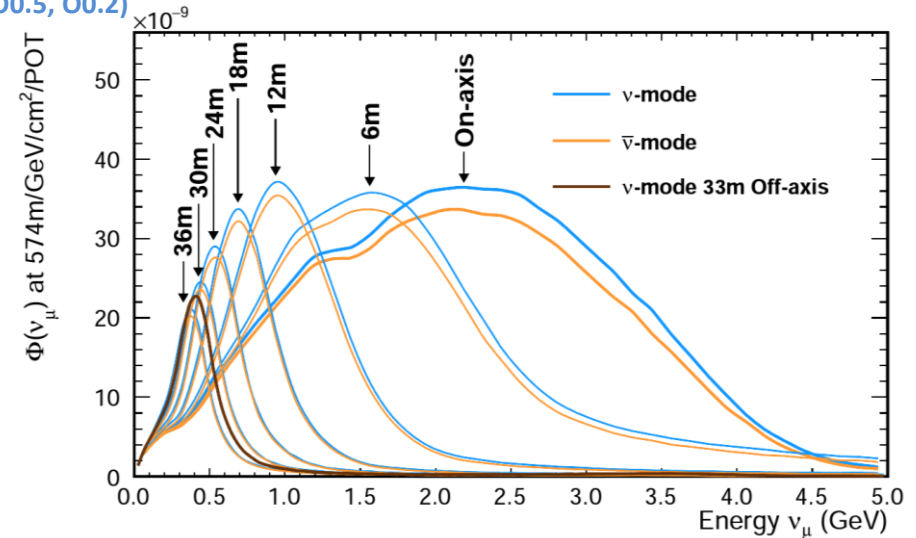
(00, 00.1)
Low threshold +
detailed Ar xsec,
minimal secondaries
(00.3, 00.4, 00.5)

LAr Detector
(ArgonCube)

Meas. ND
flux on argon

LAr response

(00.5, 00.2)

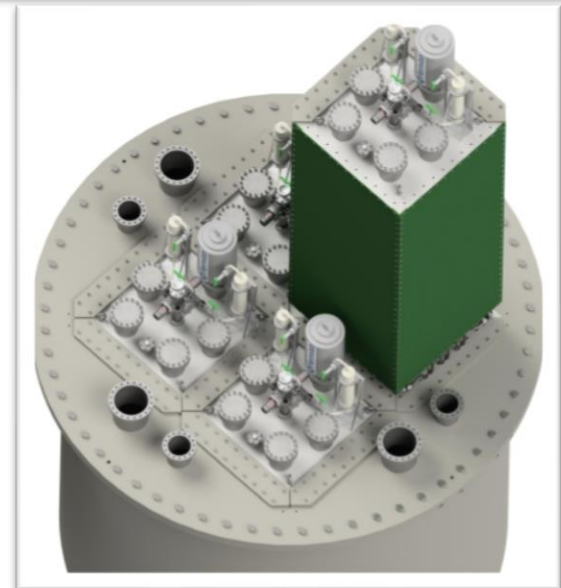
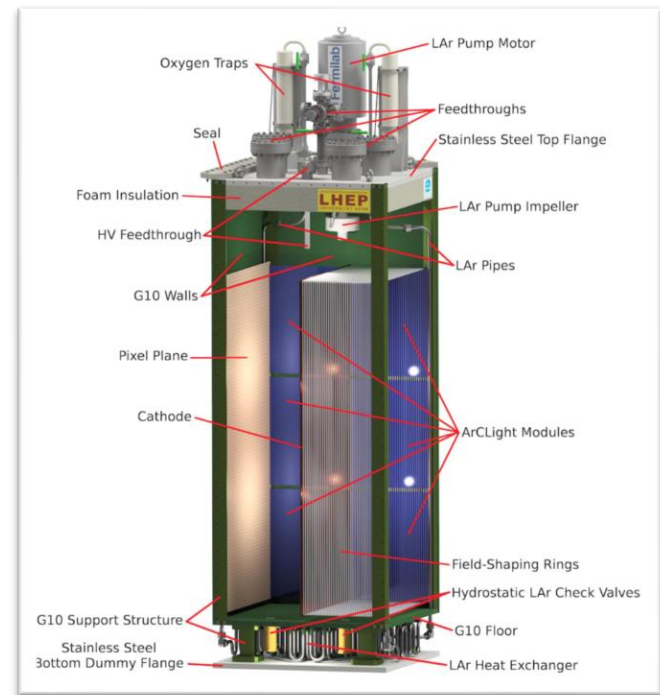


The LArTPC

- As similar as feasible to the FD to allow a Near \leftrightarrow Far translation approach to oscillation analysis.

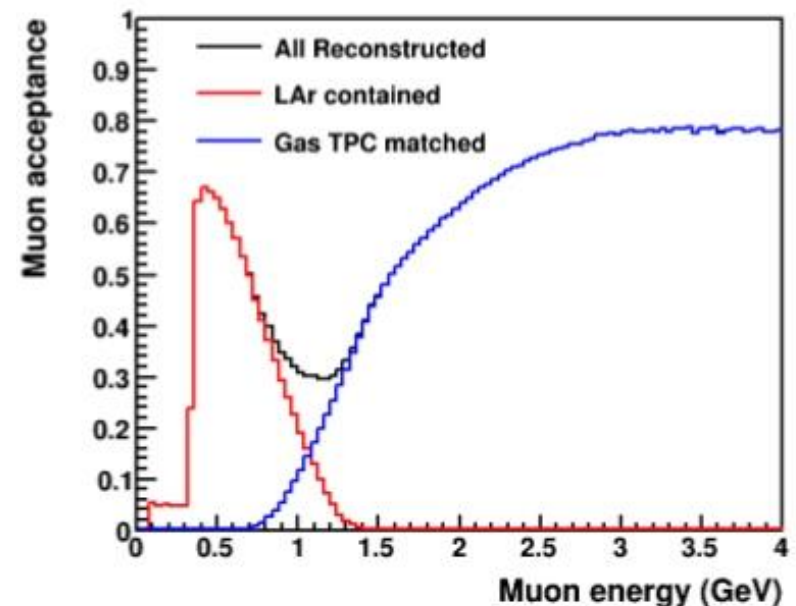
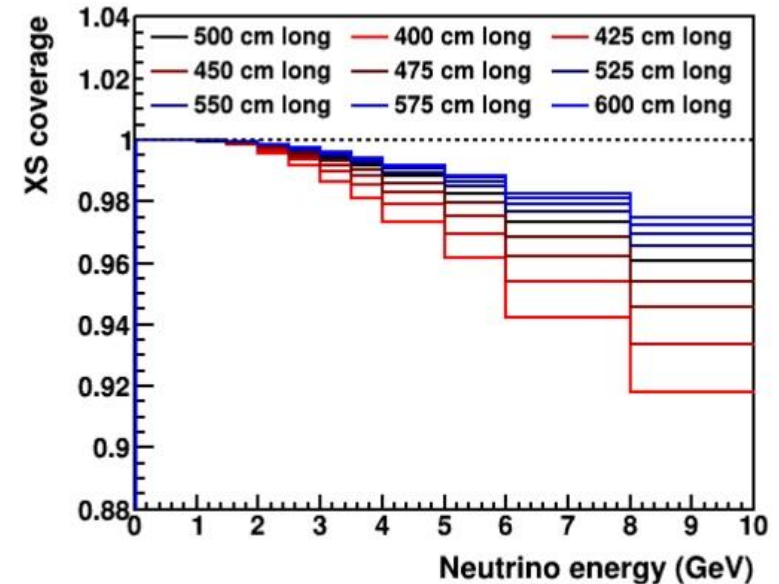
[O0 Predict the neutrino spectrum at the FD]
[O0.1 Measure interactions on argon]

- Segmented into 1x1x3m modules with thin walls (1cm G10) that have similar density to LAr.
- Pixelized readout to deal with pileup.
- Optical readout via dielectric light traps (ArcLight) provides t_0 determination.
- A 2x2 module prototype will run in NuMI next summer

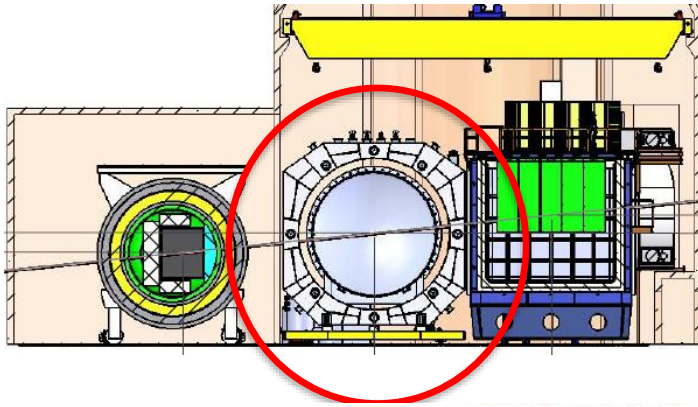


The LArTPC

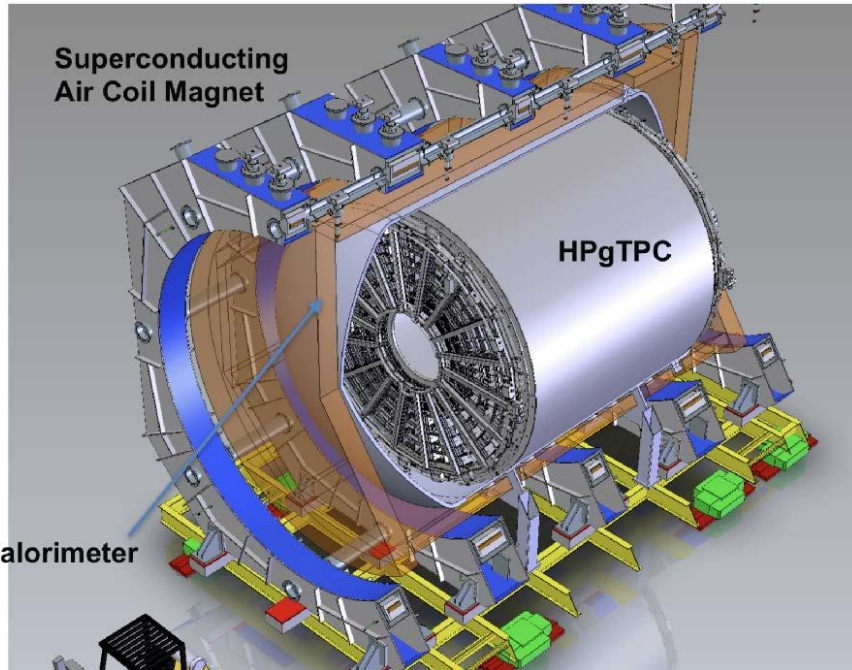
- 3m height is set by hall height and crane.
- 5m depth set by hadronic shower containment.
- 7m width:
 - 5m for shower containment
 - +1m on each side to contain side exiting muons
 - Cost effective solution
 - Increases fiducial volume by 50%
- Muons with energy $> 1\text{GeV}$ are not contained well so a spectrometer is needed downstream.



Multi-Purpose Detector Overview

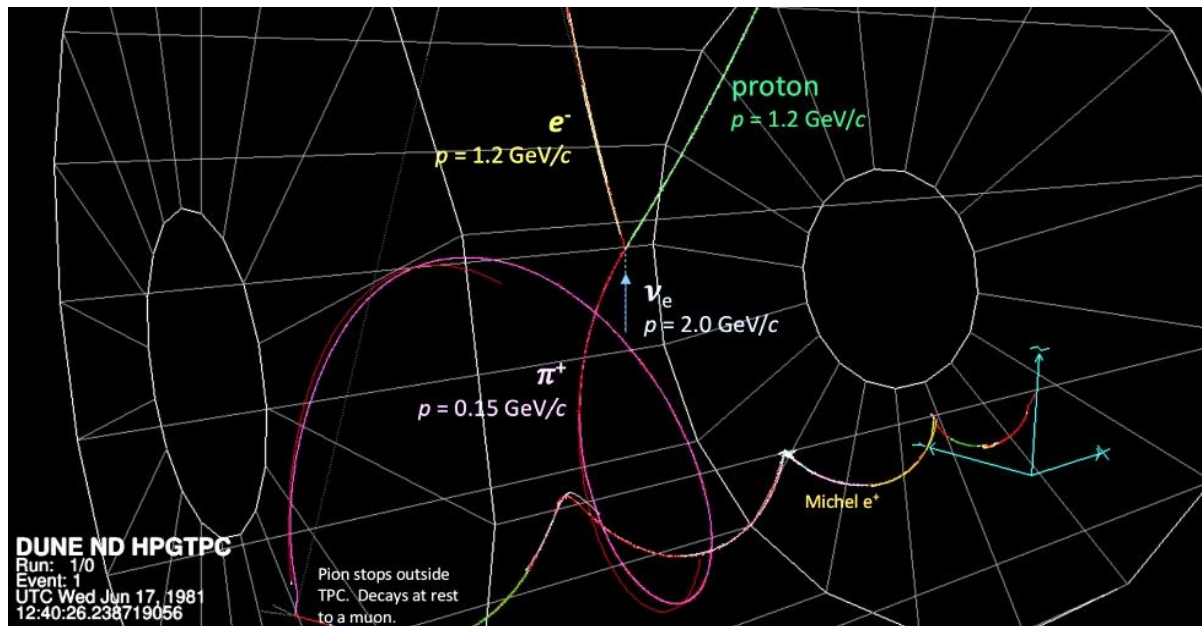


- High pressure (10bar) gas TPC + ECAL + SC magnet + μ tag
- Provides muon spectrometry for muons leaving LAr
 - LAr event containment
- Provides an independent, statistically significant event sample on Ar gas
 - Sign selection
 - Full 4π coverage
 - Very-low tracking threshold
 - Relatively few secondary interactions
- Can move off axis



Multi Purpose Detector

- Measures the momentum and sign of muons exiting the LArTPC
- [O0.2 Measure the Neutrino Energy]
- Provides a large set of well reconstructed neutrino interactions on argon
- [O0.1] to constrain the cross-section model [O0.3]



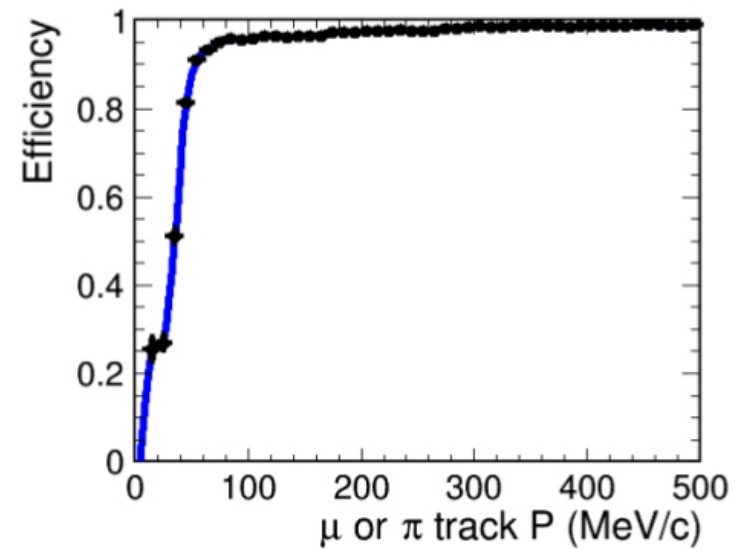
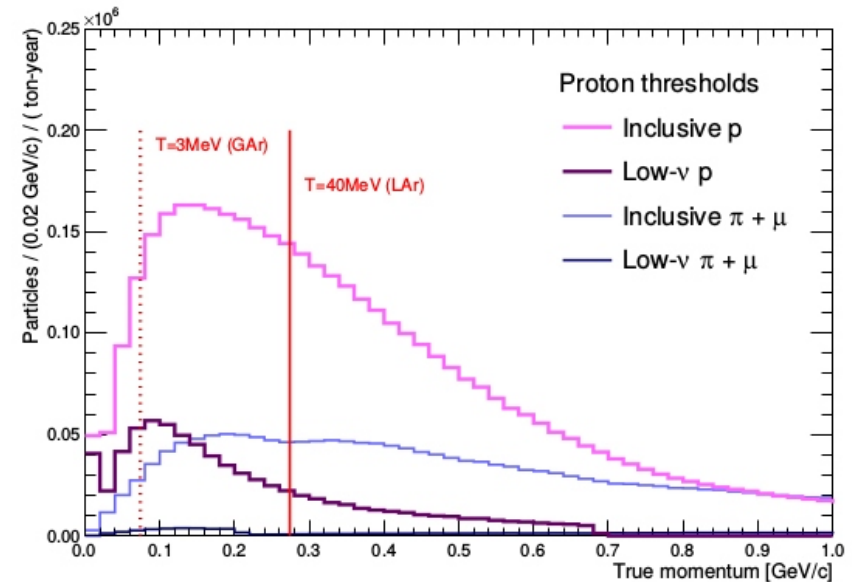
Multi Purpose Detector

Serves as a control for the LArTPC.

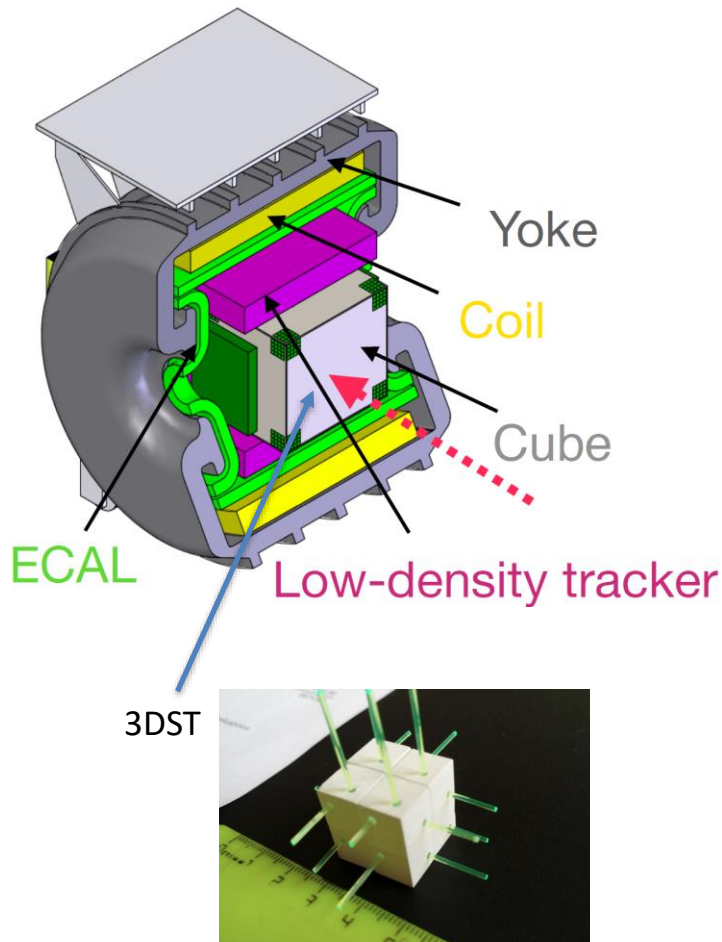
- Very low thresholds and high efficiency. Can see what the LArTPC is missing.
- Kinematic acceptance nearly 4π like the far detector
- Measures hadron energies using a more accurate & precise technique than the LArTPC.
- Measures the composition of the hadronic system.

Under Study

- Neutron performance
- Potential to set the absolute energy scale via Ks and Lambda decays



SAND – System for on-Axis Neutrino Detection

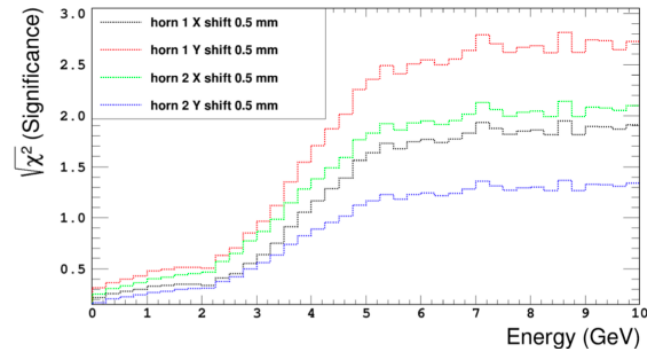


- 10.9 tons of 1cm x 1cm x 1cm scintillator cubes inside a B field.
- Projective readout with SiPMs
- Surrounding trackers and ECAL
- 14 million CC events per year
- Remains on beam axis
- Addresses two main shortcomings:
 - **Beam monitoring** (of particular importance when MPD and LArTPC are off-axis)
[O0.6 Monitor the Neutrino Beam]
 - Sensitive to neutrons, unlike Ar
[O0.2 Measure the Neutrino Energy]

SAND – System for on-Axis Neutrino Detection

Muon spectra in 3DST in 0.6T B field. Shift seen relative to nominal in one day

Stat. Error and detector effect (smearing + efficiency applied)



Muon spectra in 3DST in 0.6T B field (one day)

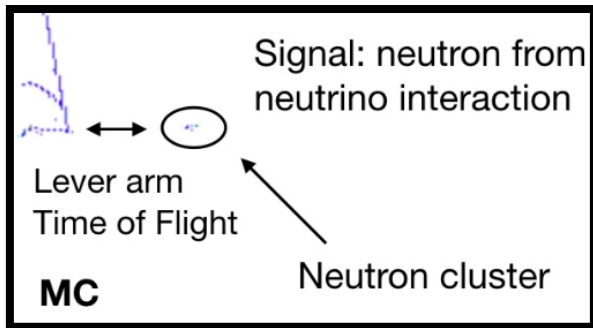
versus

rate only detector (4 7-ton modules at 0,1,2,3 m) over one week

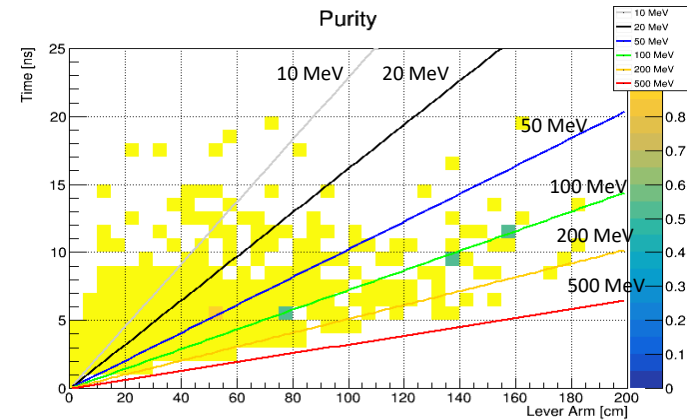
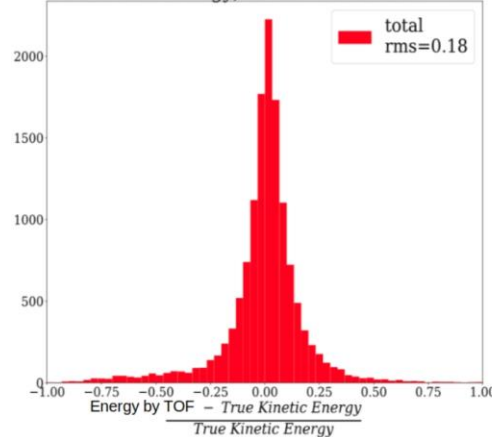
Changed beam parameter	Significance, $\sqrt{\chi^2}$	
	Rate-only monitor	3DST-S
proton target density	1.9	7.8
proton beam width	3.0	6.6
proton beam offset x	0.7	20.0
proton beam theta phi	0.2	12.5
horn 1 along x	1.9	8.8
horn 2 along x	0.7	12.8
horn 1 along y	0.2	9.9
horn 2 along y	0.4	6.3

Neutron detection with energy determination via time-of-flight

Only out of fiducial background considered. Secondaries under study.

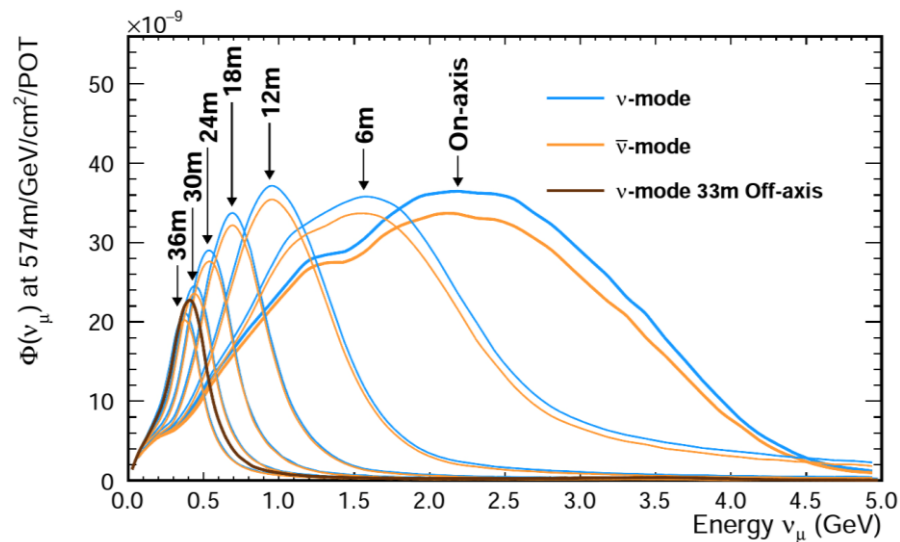
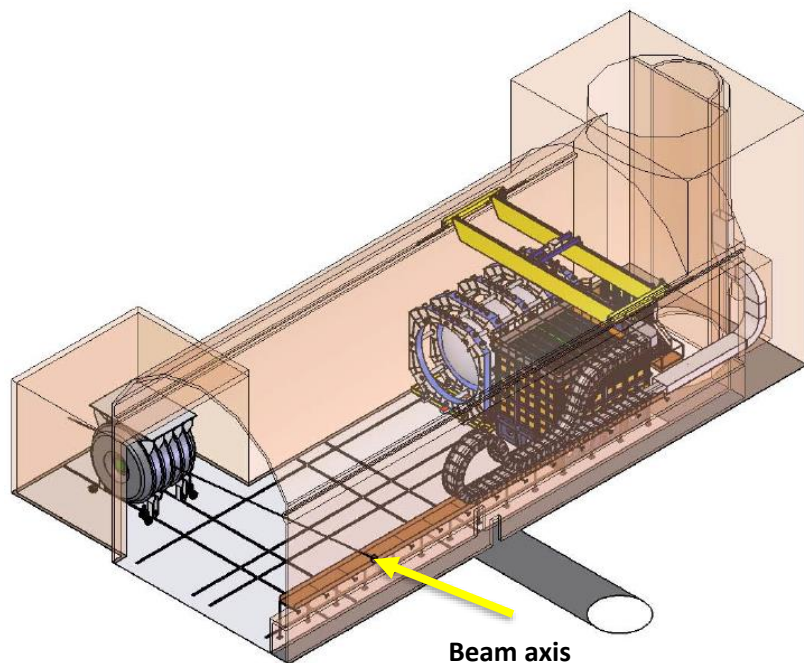


100 MeV True Energy, $0.5 \text{ m} < \text{Lever Arm} < 1.0 \text{ m}$



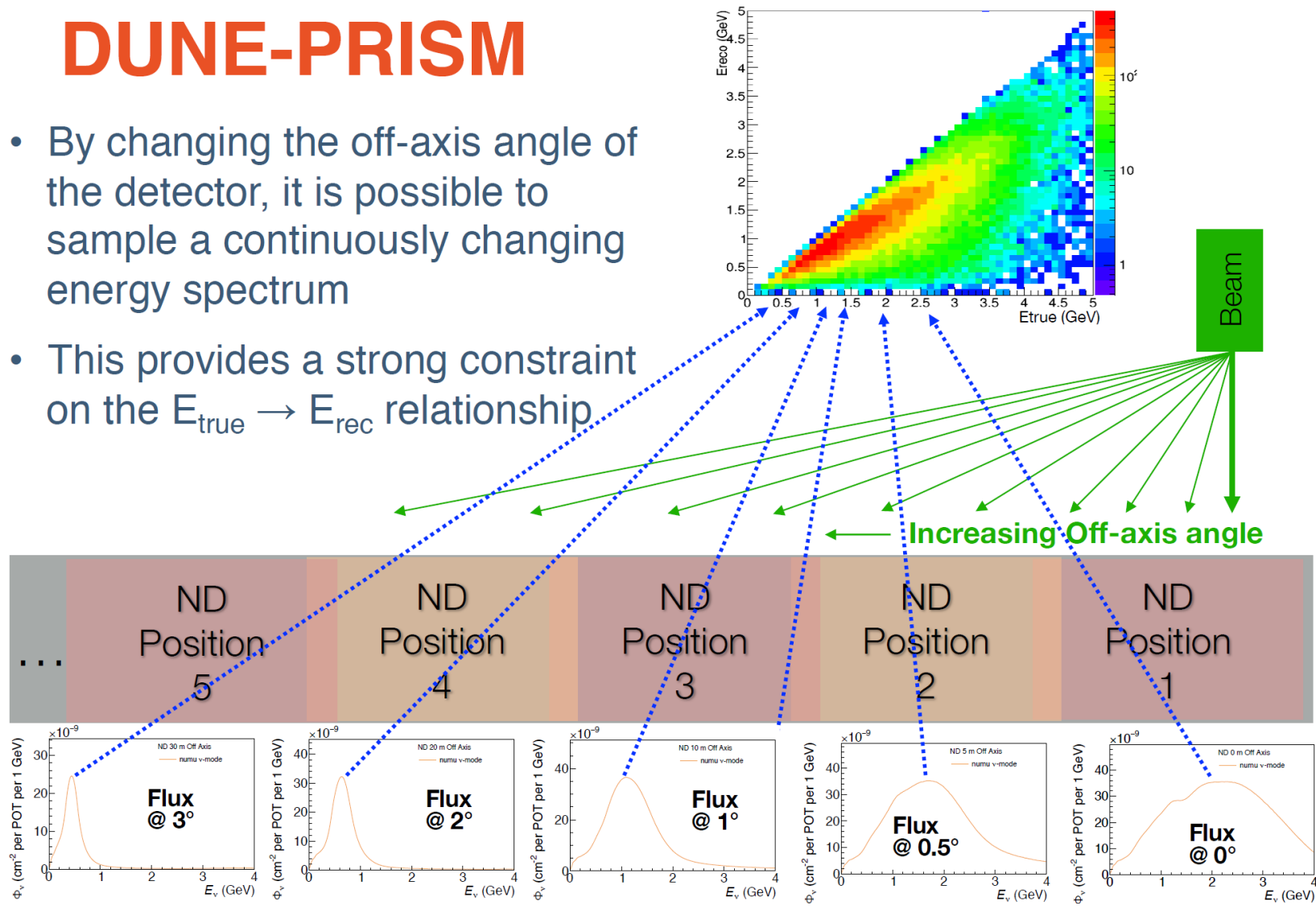
Some clarification on DUNE-PRISM

Responding to several questions/comments in the September feedback
Will try to improve presentation in the CDR as well



DUNE-PRISM

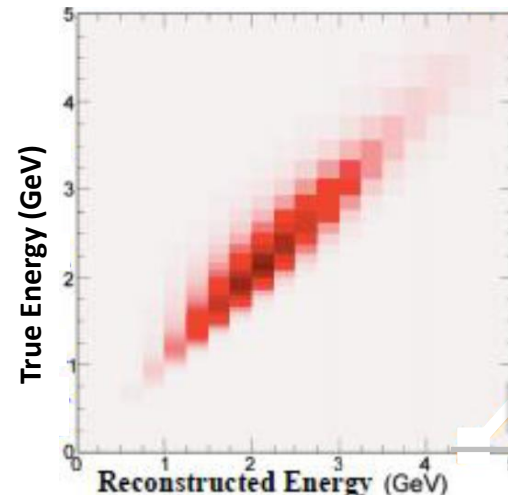
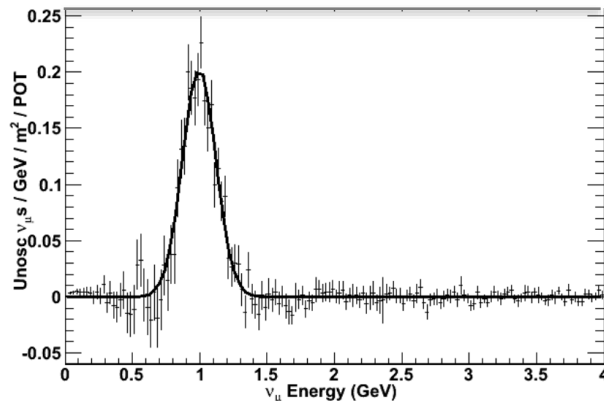
- By changing the off-axis angle of the detector, it is possible to sample a continuously changing energy spectrum
- This provides a strong constraint on the $E_{\text{true}} \rightarrow E_{\text{rec}}$ relationship



Slide from M. Wilking

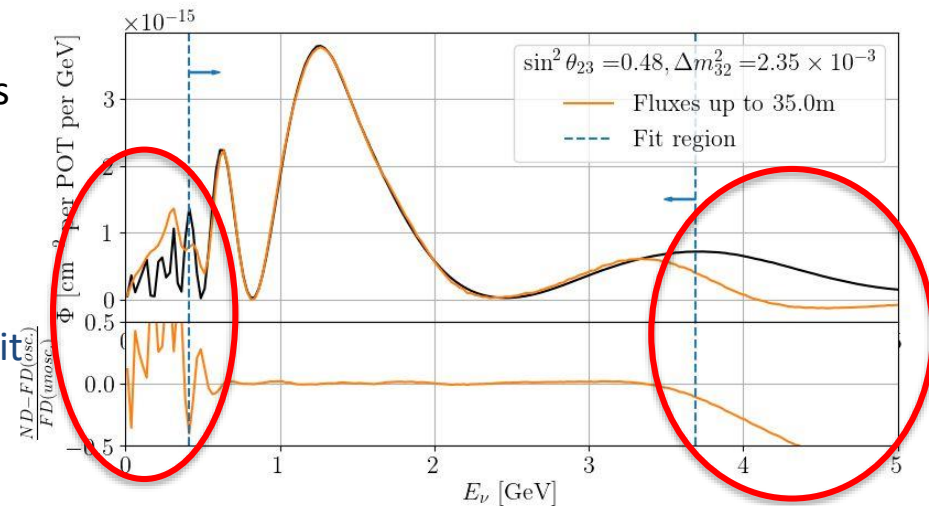
Calibrating ND response with DUNE-PRISM

- Can create Gaussian distributions at given true E_ν from linear combinations of the expected true fluxes
- Map out the response at that E_ν by comparing to the data for the same linear combination
- Repeat for different E_ν
- Ability to do this well suffers at low E_ν as you limit the transverse travel (that pulls the spectrum low) and you run out of statistics



Modeling FD spectrum using DUNE-PRISM

- Use linear combination of off-axis fluxes to generate an ND flux that looks like the oscillated FD flux, i.e., minimize ND and FD flux difference and associated systematics
 - Make oscillated FD flux prediction with given parameters (modeled fluxes)
 - Use linear combination of near detector flux slices to build FD flux prediction
 - Use coefficients of this fit to build linear sum of any ND efficiency-corrected observable
 - Apply FD efficiency
 - Gives data-driven FD prediction in this observable (minimal model dependence)
- Limits of energy range of input spectra (and stats at low end) means ability to model FD flux breaks down at high and low energy regions
- Correct those regions with model as necessary
- Those regions relatively unimportant for oscillations
- In limit that the modeled fluxes are perfect, the fit is perfect, and systematic variations are same for FD and fit model, this is a model independent measurement
- All this not quite true. Reduces but does not eliminate model dependence for FD prediction and systematic error determination



Backups

